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ABSTRACT: A size-structured shellfish population, like Alaska king crab *Paralithodes camtschaticus* poses special challenges for fishery managers and industry, alike. One often overlooked issue centers on how the size structure of the catch translates into prices and industry revenues. This investigation provides preliminary insight into wholesale price determination for frozen red king crab legs and claws, which are sold by size in the U.S. wholesale market. Bayesian bootstrapping with informative priors was used to estimate the pricing model. Two policy simulations were conducted to assess how a lower size limit might have affected wholesale prices during the 1987–88 and 1988–89 marketing years. The results show that prices-by-size can change substantially and processor revenues can rise slightly or fall depending upon how management policies affect the size structure of the catch.

INTRODUCTION

The Alaskan king crab *Paralithodes camtschaticus* fishery began a precipitous decline in 1981. Following record harvests of 185 million pounds in 1980, statewide harvests declined to 16 million pounds by 1985. The fishery remains depressed today. There is an understandable tendency by industry participants and management agencies to focus on the effects of and remedies for depressed stock conditions. However, the collapse also altered the size and species distribution of the stocks. This change in distribution impacts not only prices received at the wholesale level, but also prices received at the exvessel level.

Many fishers turned to golden king crab *Lithodes acquispinus* as a substitute for the depressed red king crab stocks. Though offsetting some of the lost red king crab revenues, economic theory suggests that the increased presence of smaller, less valuable golden crab probably depressed wholesale prices for red king crab because golden crab provide consumers a less expensive substitute.

Management strategies to rebuild the red king crab fishery or to increase industry revenues should consider the role of size and species distribution. Although both industry and regulatory agencies recognize that prices are affected by changing size and species distribution, neither is able to predict how market prices will react to changes in the distribution. Moreover, published data do not provide adequate detail on prices and quantities of king crab sold to estimate models of price determination by size and species. It follows that neither regulatory agencies nor industry are able to judge the merits of any potential management action that could alter the structure of harvest. The research presented here provides some insight into this issue. In particular, the effects of size and species on wholesale price formation is modeled on data collected directly from king crab processors. Additional detail on all aspects of the study can be found in Bibb and Matulich (1994).

Initially, we discuss the conceptual framework for a size and species structured domestic wholesale price model. However, data limitations require a compromise econometric model specification and ultimately, Bayesian bootstrapping with informative priors. The Bayesian estimates are used to simulate the effect of reducing the red king crab size limit on wholesale prices-by-size and on gross revenues. Some general policy implications are discussed in the summary and conclusions of this paper.

ANALYTICAL FRAMEWORK

Any study of price determination for food products graded by size or other quality aspects could

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provide direction for this research. However, literature reviewed focused on seafood products which are graded by size, namely groundfish, shrimp, and lobster. Price determination models for these species fall into three general categories:

(1) single-equation models of price determination at one market level, such as exvessel or wholesale levels (Waugh and Norton 1969; Gates 1974; Raizin and Regier 1986);
(2) market models, including behavioral equations for both supply and demand for either the exvessel, wholesale, or retail market level (Blomo et al. 1982; Hopkins et al. 1982; Thompson et al. 1984; Houston and Li 1989);
(3) multilevel market models that include behavioral equations for supply and demand at two or more market levels (Doll 1972; Adams et al. 1987; Wang and Kellogg 1988).

Several of the studies addressed price determination at the exvessel level where grading first occurs for many species. However, king crab is not graded by size until it is processed for sale in domestic wholesale markets. The primary domestic product form is a 20-lb box of legs and claws, graded by species and size. The industry sizing standard refers to the number of legs and claws per 10 lb (e.g., the largest packcount for red king crab is 9/12, or 9 to 12 legs and claws per 10 lb). This labeling convention began when 10-lb boxes were the industry standard and has remained even though the standard box size is now 20 lb. Wholesale prices reflect the size and species differentiation. Therefore, analysis of price determination should include the species and size-price differences, as well as substitutional relationships among the various product forms at both the wholesale and retail levels.

Conceptual Model

Wholesale prices and quantities for king crab products graded by size are determined simultaneously by buyers and sellers in the wholesale market. The conceptual model presented in equations (1)–(3) specifies important economic relationships in price and quantity formation:

$$Q^d_{ijt} = f(P_{ij}, P_{sub}, I, Z^d, e^d_{ij}) \quad ; \qquad (1)$$

$$Q^s_{ijt} = f(P_{ij}, C, TS_{ij}, Z^s, e^s_{ij}) \text{ ; and} \qquad (2)$$

$$Q^d_{ijt} \equiv Q^s_{ij} = Q_{ij} \quad ; \qquad (3)$$

where:

i = product size (9/12, 12/14, 14/16, 16/20/ 20/25, 25/up);

j = species (R for red and G for golden);

t = month;

Q^d_{ijk} = quantity of size class i and king crab species j demanded by wholesale buyers in month t;

Q^s_{ijt} = quantity of size class i and species j sold by processors in month t;

P_{ijt} = wholesale price per pound for size class i and species j of king crab in month t;

P_{subt} = wholesale price per pound for substitute products including other species and sizes of king crab and other seafood products in month t;

I_t = monthly consumer income;

C_t = processors' costs of production and storage for king crab graded by species and size in month t;

TS_{ijt} = total available supply for size class i and the species j of king crab at the beginning of month t;

Z^d_t = other variables influencing retail and wholesale demand for king crab;

Z^s_t = other variables influencing wholesale supply of king crab;

e_{ijt} = error term for demand (d) and supply (s) equations.

The specification of five size categories for both species of king crab results in a structural model containing 30 equations, 3 equations for each species and size class. There are 20 behavioral equations and 10 identities.

Equation (1) represents demand functions, where the quantity of each size and species of king crab legs demanded by wholesale buyers is determined by the price of that product (own price), price of substitutes, consumer income, other variables influencing retail and wholesale demand for king crab products (Z^d), and a random error term.

The wholesale demand for king crab is a *derived demand*, meaning that it is derived from the primary demand at the retail level. One important variable that influences both wholesale and retail demand is the type of retail market. Demand for king crab may differ depending on whether it will be sold at a seafood market, a midrange restaurant, or a white tablecloth restaurant. For example, people buying king crab at seafood markets may prefer a different size or species than those eating at white tablecloth restaurants. Another important characteristic of wholesale demand, which may influence prices and quantities, is the relationship between the wholesale buyer and seller. Large- volume buyers, or those with long-term relationships with the processors, undoubtedly are able to obtain product at more favorable terms than buyers who purchase small volumes or do not have an established relationship with the processor.

Equation (2) represents the quantity of various sizes of red and golden king crab supplied to the wholesale market by seafood processors. Quantity supplied is a function of own price, costs of production, the total available supply of both red and golden king crab throughout the marketing year, other factors which influence the supply of king crab (Z^s), and a random error term.

Equation (3) represents the market-clearing identity. It requires the quantity supplied of a particular product equal the quantity demanded each month.

The sets of supply-and-demand equations for each product form are related because consumers conceivably consider different sizes and species of king crab as possible substitutes for each other. Adjacent sizes of the same species are probably substitutes. Therefore, prices of some substitute sizes and species of king crab appear as explanatory variables in each equation. For example, Red 12/14 and 16/20 presumably substitute for Red 14/16. Some sizes of the less valuable golden king crab may also substitute for red king crab, particularly in the smaller red size classes.

In the structural model specified in equations (1)–(3), quantities and prices of the different species and size classes are endogenous, i.e., their values are simultaneously determined within the system of equations. Other variables specified in the model, such as income, price of non-king crab substitutes, and processor costs, are exogenous variables. Their values are determined outside the model. There are 20 endogenous variables and 13 exogenous variables specified in this system. Additional variables represented as Z^d or Z^s are also exogenous.

Data Considerations

Empirical estimation of the general simultaneous equation system given in equations (1)–(3) was complicated by a variety of data problems. The most notable problem was the absence of published wholesale price and quantity data. Both the National Marine Fisheries Service (NMFS) and the Urner Barry Seafood Price Current (SPC) now report weekly king crab prices-by-size, but neither reports associated quantities sold. Moreover, NMFS started differentiating king crab prices by species and pack count in 1989 — less than a year prior to the start of this study. Accordingly, major U.S. shorebased processors were surveyed. Daily wholesale price (FOB Seattle) and corresponding quantity-sold data were gathered for two complete seasonal years beginning October 1987 and ending September 1989 (some cooperating processors could not retrieve data prior to May 1987, which confined this study to the two seasonal years beginning October 1987). These data reflect approximately 40% of the 1988/89 domestic sales of king crab graded by size and packed in 20-lb boxes. Individual daily sales data were aggregated to a monthly basis to protect confidentiality of participating processors/buyers.

Total available supplies (INV_t) of red king crab graded by size were computed based on cumulative annual sales of the processors surveyed less their monthly sales (Q_t^s). This measure of supply is presumed to be known before the marketing season because processors know total catch, exports to Japan, and the general size distribution of bulk processed crab. The inventory variable in October of each year was set equal to total seasonal-year sales of the particular size class. Beginning stocks in successive months were calculated by subtracting monthly sales from the prior month inventory. No such available supply measure could be compiled for golden king crab because they are managed without a quota or harvest guideline range, and harvests occur during each month of the year. Absence of this one variable limited the analysis to the study of red king crab pricing by size.

Prior annual king crab demand research by Hanson (1987), Greenberg (1990), and Matulich et al. (1990) was helpful in identifying other potential components of demand. The effect of a price change in a substitute seafood product, for example, was measured by two alternative variables: (1) the monthly average wholesale price of 8–10 oz Australian rock lobster tails ($PLOBA_t$), and (2) 2-lb live Maine lobsters ($PLOBM_t$). Data for both variables were constructed from SPC. As usual, the prices of these substitutes were hypothesized to be positively correlated with king crab price. Per capita monthly expenditures in restaurants ($PCREST_t$) measured how changes in consumer income over the 2-year study affected retail and, thus, wholesale demand for red king crab. The $PCREST_t$ variable was derived from U.S. Department of Commerce, Bureau of Economic Analysis, and Bureau of Census data. Exvessel price (PEXR) is a major component of processors' costs that should be positively related to wholesale price. However, because the Alaska red king crab season was limited to only a few weeks each fall, seasonal average exvessel price took on only two values throughout the study, $4.00/lb in 1987–88 and $5.08/lb in 1988–89 (data were obtained from the Alaska Department of Fish and Game). No prices were adjusted for inflation. More detailed descriptions of the data, sources, and methods used to calculate the data can be found in Bibb and Matulich (1994).

One of the most serious data deficiencies for this analysis concerns the absence of specific demand characteristic data, the Z_d in equation (1). Data related to wholesale buyer characteristics were obtained from the processor survey. Unfortunately, one processor declined to identify individual buyers, so no buyer characteristics could be used. This situation prevented two-stage least squares estimation of the structural model in equations (1)–(3). Insufficient observations on exogenous variables prevented constructing good instrumental variables. Moreover, the reduced-form equations were estimated using only 40% of industry-wide sales. Such measurement error in the quantity variables also contributed to the need for a compromise specification.

Empirical Model

The empirical model specification is a partial reduced form of equations (1)–(3) in which some endogenous variables remain as explanatory variables. Prices of adjacent red king crab sizes are included as explanatory variables to capture the effects of substitute sizes on price. However, this inclusion of endogenous explanatory variables introduces simultaneity bias. Nevertheless, OLS is supported by Kennedy (1989) in the context of small samples, such as this study.

Four additional considerations impacted final model specification and estimation. First, the September 1989 observation was dropped from the data set. Price declined with shrinking end-of-season inventory as processors sold off stock prior to entering the 1989–90 season. Consequently, a 0–1 indicator variable containing zeros in all months except September 1989 was used to test outlier status. The indicator variable was significant at the 99% level; September 1989 was dropped from the data set. The second consideration involved dropping the income variable ($PCREST_t$) from the model. This variable was not significant, probably because consumer income did not change enough over the 2-year period to significantly impact wholesale prices. The third consideration involved dropping golden crab as a substitute for red crab. Initially, the size-specific equations were estimated with the price of both red and golden substitute sizes as explanatory variables. However, high correlation between price variables forced exclusion of the golden crab prices. Finally, all wholesale price equations were estimated without an intercept so that the coefficient on exvessel price, which is one value per season, could be interpreted as the margin of wholesale price over exvessel price. Including an intercept would result in exvessel price acting only as an indicator variable for the marketing year.

Maine lobster was not a statistically significant substitute, so it was dropped from OLS estimation. The final results of OLS estimation and *t*-values associated with the parameter estimates in parentheses are given in equations (4)–(8) below:

$$\begin{aligned} PR9/12 = \; & \underset{(0.885)}{0.5853\,PEXR} + \underset{(1.536)}{0.5369\,PR12/14} - \\ & \underset{(-0.697)}{0.0049\,INV9/12} + \underset{(2.395)}{0.1892\,PLOBA} \end{aligned} \tag{4}$$

$$R^2 = 0.9995 \quad F = 7{,}900$$

$$\begin{aligned} PR12/14 = \; & \underset{(2.691)}{1.0569\,PEXR} + \underset{(0.731)}{0.1135\,PR9/12} + \\ & \underset{(1.820)}{0.3773\,PR14/16} - \underset{(-1.259)}{0.0009\,INV12/14} + \\ & \underset{(1.790)}{0.0732\,PLOBA} \end{aligned} \tag{5}$$

$$R^2 = 0.9998 \quad F = 15{,}656$$

$$\begin{aligned} PR14/16 = \; & \underset{(1.928)}{0.5513\,PEXR} + \underset{(2.532)}{0.4728\,PR12/14} + \\ & \underset{(1.619)}{0.2921\,PR16/20} - \underset{(-1.976)}{0.0007\,INV14/16} \end{aligned} \tag{6}$$

$$R^2 = 0.9997 \quad F = 18{,}483$$

$$\underset{}{PR16/20} = \underset{(2.505)}{0.9735\ PEXR} + \underset{(2.362)}{0.3764\ PR14/16} + \underset{(0.290)}{0.0343\ PR20/25} - \underset{(-2.548)}{0.0019\ INV16/20} + \underset{(4.219)}{0.0886\ PLOBA} \quad (7)$$

$$R^2 = 0.9998 \quad F = 15{,}179$$

$$PR20/25 = \underset{(2.647)}{1.0465\ PEXR} + \underset{(1.212)}{0.2751\ PR16/20} - \underset{(-4.634)}{0.0213\ INV20/25} + \underset{(2.842)}{0.1369\ PLOBA} \quad (8)$$

$$R^2 = 0.9993 \quad F = 7{,}020$$

Signs on all coefficient estimates are consistent with economic theory. The coefficients of determination (R^2) have been adjusted, through the SAS regression procedure for estimation without an intercept term. The high explanatory power of these models, as evidenced by R^2 values very close to 1.0 is, in part, a feature of using time-series data and estimating a model with highly correlated explanatory variables that are also highly correlated with the dependent variable. Both the dependent and explanatory variables reflect similar time trends.

The *F*-statistics for equations (4)–(8) indicate that not all the coefficient estimates are equal to zero at the 95% level. Similarly, one-tailed *t*-tests suggest that all but four coefficient estimates in these equations are significant at the 90% level. Variables not significant at the 90% level include exvessel price and remaining inventory in equation (6), PR9/12 in equation (7), and PR20/25 in equation (9).

Bayesian Bootstrap Estimates

Two features of the "compromise" OLS estimation motivated use of Bayesian bootstrapping with informative priors to obtain better estimates for subsequent simulation. First, the OLS parameter estimates were based upon a small sample of 23 monthly observations. Second, while the OLS parameter estimates revealed signs consistent with economic theory, use of sign restrictions as prior information and Monte Carlo sampling (bootstrapping) will yield parameter estimates that are more efficient in the sense of minimizing expected quadratic loss in parameter estimation. In particular, use of prior information in conjunction with the observed data yields best-guess or optimal parameter estimates in a Bayesian context.

The Bayesian estimates were obtained by bootstrap sampling using minimally restrictive prior information, i.e., that all substitute prices are positively signed, exvessel price is positively signed, and available supplies (stocks) are negatively signed. Ten thousand samples were bootstrapped using the Bayesian inequality constrained estimation (Geweke 1986) algorithm (Shazam Version 6.1, 1990).

Unlike OLS, Bayesian estimates are not evaluated in terms of their sampling properties. Classical hypothesis test statistics, including *t*-statistics and *F*-statistics, can no longer be used to test hypotheses because the repeated sampling context of these test procedures are no longer valid. Instead, Bayesian point estimates are interpreted as the best that can be obtained, given the prior and sample information and the particular loss function (i.e., quadratic loss). The numerical standard errors of these parameter estimates indicate how precisely the parameter estimates represent the mean of the posterior distribution. A desirable outcome of the bootstrapping process is that it provides an estimate of the probability that the *a priori* restrictions hold. That is, one can evaluate the consistency of the restrictions with the observed data within the context of the model specified.

The bootstrap estimates with numerical standard errors in parenthesis are provided below in equations (9)–(13):

$$PR9/12 = \underset{(0.0054)}{0.7661\ PEXR} + \underset{(0.0028)}{0.4302\ PR12/14} - \underset{(0.650E\text{-}4)}{0.0077\ INV9/12} + \underset{(0.0007)}{0.2165\ PLOBA} \quad (9)$$

58.31% of replications satisfied constraints

$$PR12/14 = \underset{(0.0042)}{1.0365\ PEXR} + \underset{(0.0014)}{0.1677\ PR9/12} + \underset{(0.0021)}{0.3396\ PR14/16} - \underset{(0.739E\text{-}5)}{0.0010\ INV12/14} + \underset{(0.0004)}{0.0657\ PLOBA} \quad (10)$$

63.47% of replications satisfied constraints

$$PR14/16 = \underset{(0.0029)}{0.5689\ PEXR} + \underset{(0.0018)}{0.4521\ PR12/14} + \underset{(0.0021)}{0.3075\ PR16/20} - \underset{(0.377E\text{-}5)}{0.0007\ INV14/16} \quad (11)$$

86.64% of replications satisfied constraints

$$\begin{aligned} PR16/20 = {} & \underset{(0.0044)}{0.8617\ PEXR} + \underset{(0.0020)}{0.3654\ PR14/16} + \\ & \underset{(0.1047)}{0.1087\ PR20/25} - \underset{(0.846E\text{-}5)}{0.0016\ INV16/20} + \\ & \underset{(0.0002)}{0.0841\ PLOBA} \end{aligned} \quad (12)$$

58.95% of replications satisfied constraints

$$\begin{aligned} PR20/25 = {} & \underset{(0.0035)}{0.9692\ PEXR} + \underset{(0.1976)}{0.3206\ PR16/20} - \\ & \underset{(0.478E\text{-}4)}{0.0208\ INV20/25} + \underset{(0.0005)}{0.1298\ PLOBA} \end{aligned} \quad (13)$$

87.14% of replications satisfied constraints

Coefficient estimates from the Bayesian procedures are of similar magnitude as those from the OLS estimates in (4)–(8), with one exception. The estimate on PR16/20 in equation (12) is three times that of the OLS coefficient estimate in equation (7). The probability that the sign restrictions are satisfied within the context of the specified model ranges from 58% to 87%. The bootstrap parameter estimates are used for subsequent analysis of red king crab prices.

Calculating Reduced-form Multipliers

Conventional single-equation econometric analysis permits direct interpretation of the parameter estimates. However, because all five equations (9–13) are linked through the use of endogenous, explanatory variables, it is necessary to remove this cross-equation influence. That is, it is necessary to capture the direct effect of a change in an exogenous variable in a specific equation and the indirect effect as that change filters through the system of equations.

The reduced form of equations (9)–(13) expresses price for each size category as a function of only exogenous variables. Coefficient estimates from the reduced-form equations are calculated by postmultiplying the 5x7 matrix of coefficient estimates on exogenous variables by the inverse of a 5x5 matrix having ones on the diagonal and the negatives of the coefficient estimates on endogenous variables (price) on the off-diagonal:

$$R = A^{-1}B, \quad (14)$$

where:

R = 5x5 matrix of reduced-form coefficients,
A^{-1} = 5x5 inverse matrix involving coefficients on endogenous variables, PR9/12 - PR20/25, and
B = 5x7 matrix of coefficients on exogenous variables.

The reduced-form coefficients are impact multipliers that quantify the effect of a one-unit change in an exogenous variable on prices given the relationships between all variables inherent in the five-equation model. Table 1 contains the reduced-form multiplier matrix, R.

The reduced-form multipliers indicate that processors operate ostensibly on a cost-plus pricing basis, where the parameter estimate on exvessel price times the value of exvessel price sets the margin for wholesale price over exvessel price. This conclusion is consistent with Greenberg (1990). From 1987–89, this margin was approximately 1.5 to 2.0 times input costs, as measured by exvessel price. The greatest margins occur with the 14/16 and 12/14 pack counts. When the cost-plus base for wholesale price is determined, prices are adjusted by remaining inventories and price of the lobster tail substitute. Because inventory is measured in 1,000 lb quantities, small negative multipliers on INV9/12 through INV20/25 indicate that changes in stock levels has only very minor impact on general price level. Lobster prices, however, have a relatively important influence on the wholesale price of king crab in this model. A $1.00 increase in the price of lobster at the sample mean values yields from $0.11/lb to $0.28/lb increase in the price of red king crab.

SIMULATIONS

Following an ex-post simulation to evaluate how well the estimated model reproduced historical prices over the 1987–89 period, two policy simulations were conducted. The policy simulations were designed to offer a preliminary assessment of how a lower size limit might have affected wholesale prices and, thus, processor revenue during the 1987–88 and 1988–89 marketing years. Implications also are drawn with regard to likely changes in exvessel price and revenue.

Simulation of the 1987–89 Estimation Period

Simulation of the historical data is accomplished by using the reduced-form coefficient matrix in Table 1 and the values of exogenous variables in the original data set. Two goodness-of-fit statistics confirm that, in general, the model simulates the historical data very

Table 1. Reduced-form multipliers for red king crab wholesale prices.

Dependent Variable	Explanatory Variables[1]						
	PEXR	PLOBA	INV9/12	INV12/14	INV14/16	INV16/20	INV20/25
PR9/12	1.6230	0.2816	-0.00840	-0.00058	-0.00016	-0.00011	-0.00016
PR12/14	1.9919	0.1512	-0.00171	-0.00134	-0.00038	-0.00026	-0.00037
PR14/16	2.0117	0.1128	-0.00087	-0.00069	-0.00104	-0.00072	-0.00100
PR16/20	1.7636	0.1444	-0.00033	-0.00026	-0.00040	-0.00195	-0.00272
PR20/25	1.5346	0.1761	-0.00011	-0.00008	-0.00013	-0.00063	-0.02165

[1] Variable Definitions:
PR - Domestic wholesale price of a size-graded 20-lb box of red king crab legs and claws.
PEXR - Seasonal average exvessel price for red king crab.
PLOBA - Price of 8–10 oz frozen Australian lobster tails, mid-Atlantic coast.
INV - Remaining annual inventory of size-graded product, seasonal year, measured in thousands of pounds.

well. The mean absolute percentage errors (MA%E) presented in Table 2 are very low — less than 2.2% in all cases. The maximum error for a single observation is only 9% (Red 20/25). A second simulation statistic, Theil's inequality coefficient (*U*), scales the root mean square simulation error (deviation of predicted value from actual value) so that the value of *U* is between 0 and 1 (Pindyck and Rubinfeld 1981). An inequality coefficient of zero indicates a perfect forecast. Table 3 presents values for this statistic and its decomposition into sources of simulation error. The bias proportion (U^M) measures systematic error or the average deviation between simulated and actual data. The regression proportion (U^R) also measures systematic error by evaluating the slope coefficient from a regression of changes in actual values on changes in predicted values. U^R increases as the slope coefficient differs from 1.0. Both U^M and U^R should be close to zero. The disturbance proportion, U^D measures the unsystematic proportion of forecast error attributable to random disturbances. U^D will be close to 1.0 if the other two sources of error are near zero. The inequality coefficients for the simulations were near zero, so the model performs well in predicting actual prices. Both the bias (U^M) and regression (U^R) proportions are <1%, indicating that the majority of forecast error is due to random disturbances and not systematic error in the estimation.

Table 2. Goodness-of-fit statistics for ex-post simulation of historical baseline data for red king crab.

Endogenous Variable	Lower Range Absolute % Error	Mean Absolute Absolute % Error	Upper Range Absolute % Error
PR9/12	0.0003	0.0184	0.0641
PR12/14	0.0014	0.0124	0.0449
PR14/16	0.0011	0.0170	0.0431
PR16/20	0.0004	0.0135	0.0362
PR20/25	0.0004	0.0211	0.0892

Table 3. Theil's statistics for ex-post simulation of historical baseline data for red king crab.

Endogenous Variable	(*U*) Inequality Coefficient	(U^M) Bias Proportion	(U^R) Regression Proportion	(U^D) Disturbance Proportion
PR9/12	0.0122	0.000	0.034	0.966
PR12/14	0.0085	0.008	0.068	0.924
PR14/16	0.0107	0.001	0.01	0.985
PR16/20	0.0093	0.000	0.025	0.975
PRRR20/25	0.0135	0.001	0.008	0.991

Simulating the Consequences of a Reduced Size Limit

Any consideration of a reduced size limit implies a new, smaller grade. However, there is no way to predict prices and sales of smaller crab. Nor is there any statistical way to estimate how a new, smaller grade will affect the substitutional relationships across the larger grades. Accordingly, this analysis simulates the influence of a size-limit reduction by increasing the available supply of the smallest current size category (20/25 count). This increase in supply of 20/25s is achieved under two different policy scenarios, each reflecting alternative ways that a size-limit policy change might be achieved. The economic consequences of the policy change is evaluated by comparing the resulting predicted prices and thus, industry revenues, with those of an historical baseline.

The historical baseline uses the multiplier matrix in Table 1 to hindcast monthly prices-by-size, assuming actual historical monthly inventories, exvessel

Table 4. Total pounds of red king crab sold and distribution by size under historical conditions and two alternative policy scenarios, 1987–88 and 1988–89.

Year	Product	Historical	Policy Scenario 1	Policy Scenario 2
1987–88	9/12	46,480	44,539	35,895
		4.44%	4.25%	3.43%
	12/14	306,380	293,870	295,804
		29.23%	28.04%	28.23%
	14/16	357,080	342,165	347,157
		34.07%	32.65%	33.13%
	16/20	274,390	262,929	264,363
		26.18%	25.09%	25.22%
	20/25	63,690	104,802	104,802
		6.08%	10.00%	10.00%
	Total Sales	1,048,020	1,048,020	1,048,020
		100.00%	100.00%	100.00%
1988–89	9/12	22,580	21,549	14,376
		3.23%	3.08%	2.06%
	12/14	201,460	192,259	193,936
		28.80%	27.49%	27.72%
	14/16	224,520	214,266	217,020
		32.10%	30.63%	31.03%
	16/20	211,120	201,478	203,729
		30.18%	28.80%	29.12%
	20/25	39,820	69,950	69,950
		5.69%	10.00%	10.00%
	Total Sales	699,500	699,500	699,500
		100.00%	100.00%	100.00%

prices, and lobster prices. Cumulative industry revenues measured in October 1989 dollars are then calculated. Predicted revenues to processors during the estimation period were calculated by compounding monthly revenues by the average prime interest rate on short-term loans over a 24-month period (9.91%). Total revenues reflect only the portion of the industry represented by the survey participants.

The two reduced size-limit scenarios predict prices and revenues assuming quantities sold are identical to 1987–88 and 1988–89 levels. These represent policies of reducing the size limit while holding total annual harvest constant. The distribution of product is adjusted so that 20/25s represent 10% of total annual quantities sold in each year instead of 6.1% and 5.7%, respectively. Table 4 presents the actual total pounds sold and distribution by size. Scenario 1 assumes a uniform impact on harvest. Redistribution of total harvest is achieved by subtracting an equal percentage amount from the four larger pack counts (0.958% in the first year and 0.954% in the second year). Scenario 2 assumes the reduced size limit will have a disproportionate impact on the larger sizes. This possibility was modeled by reducing each of the four larger size categories to be the same total poundage, i.e., 25% of the increase in 20/25-count quantity sold is removed from each of the four larger pack counts.

Table 5. Weighted average annual wholesale prices-by-size (in $/lb) of red king crab legs and claws under historical and alternative policy scenarios, 1987–88 and 1988–89.

Year	Product	Historical	Policy Scenario 1	Policy Scenario 2
1987–88	9/12	$10.25	$10.27	$10.31
	12/14	9.91	9.91	9.92
	14/16	9.30	9.29	9.29
	16/20	8.75	8.69	8.69
	20/25	7.89	7.38	7.38
1988–89	9/12	$12.09	$12.10	$12.13
	12/14	12.19	12.20	12.20
	14/16	11.64	11.64	11.64
	16/20	10.79	10.77	10.77
	20/25	9.78	9.41	9.41

Predicted Prices

Weighted average annual prices are summarized in Table 5. These results show that, as expected, a reduced size-limit policy has the greatest impact on price of the smallest crab. Average prices of 20/25s dropped $0.50/lb in the first year and $0.37/lb in the second year due to the increased sales. Price of the adjacent pack count (16/20s) dropped $0.06–$0.08/lb the first year but only $0.02–$0.03/lb the second year. Differences in magnitudes between years is a consequence of cumulative quantity sold; 33% more crab were sold in the 1987–88 marketing year. The particular policy scenario had little effect on the level of price changes. A notable exception relates to the price of 9/12s under Scenario 2: Price increased $0.04–$0.06/lb. This equal quantity scenario reflects a considerably reduced harvest of the largest crab. The large percentage reduction in the first-year volume sold of 9/12-count crab more than offset any weak substitution effects that trickle down from the much less expensive 20/25 count crab.

Predicted Revenues

Total revenues (October 1989 dollars) generated under each scenario are listed in Table 6. These revenue predictions portray a partial image of how industry well-being is likely to be affected by a reduced size-limit policy. It is immediately apparent

Table 6. Total revenue from red king crab sales under historical baseline conditions and two scenarios of sales and product distribution (value as of October 1, 1989).

Product	Historical	Policy Scenario 1	Policy Scenario 2
9/12	$ 781,401	$ 755,948	$ 575,070
12/14	5,726,174	5,530,418	5,525,044
14/16	6,062,893	5,976,899	5,877,960
16/20	4,803,874	4,688,176	4,609,274
20/25	937,131	1,504,613	1,502,655
Total	$18,311,473	$18,456,054	$18,090,003

that unlike prices, processing revenues depend upon the way in which a size-limit reduction is achieved. Revenues are shown to rise slightly under Scenario 1 and drop under Scenario 2. Revenues rise from $18.31 million to $18.46 million when total harvest is held constant and the size distribution is changed in a constant percentage (Scenario 1). Only the 20/25 count revenues rise despite the $0.37–$0.50/lb price drop. The 10% increase in quantity sold of 20/25s exceeded the 4–6% price decrease.

Total revenues fall from $18.30 million to $18.09 million when the redistribution involves a constant quantity reduction (harvest) by size (Scenario 2). Changes in individual pack count revenues follow a pattern similar to Scenario 1. Even the 9/12 revenues drop despite the $0.04–$0.06/lb average price rise. This result is a consequence of the relatively small percentage increase in price being more than offset by the larger percentage decline in quantity sold.

SUMMARY AND CONCLUSIONS

A size-structured shellfish population, such as Alaskan king crab, poses special challenges for fishery managers and industry, alike. One often overlooked issue centers on how the size structure of the catch translates into prices and industry revenues. This investigation provides preliminary insight into wholesale price determination for frozen king crab legs and claws, which are sold by species and size in the U.S. wholesale market.

Seafood processors representing approximately 40% of domestic king crab sales in 1988 provided information on individual sales of king crab products from May 1987 through December 1989. This data was aggregated to generate a data set containing monthly observations on quantity sold and wholesale price for five sizes of red king crab. Some important elements of retail and wholesale demand were not available to develop a theoretically complete model specification of wholesale price. A compromise model specification had to be developed.

The results of this study provide further evidence that processors are pricing largely on a cost-plus basis, with exvessel price determining the general price level from year to year. However, total available supply of each size of crab legs and the price of substitute seafood products, in this case lobster, are also important in explaining price levels and movements over time. Adjacent sizes of red king crab are direct substitutes to wholesale buyers. Therefore, changes in price or available quantities of one size articulate price movements in other sizes. An increase in the available supply of small red king crab legs and claws generally has a negative effect on all wholesale prices.

The reduced-form multiplier matrix derived from the Bayesian bootstrap coefficient estimates was used to simulate wholesale price response to reducing the size limit. Such a management action would result in red king crab legs and claws that are smaller than any size currently marketed, except possibly some crab imported from the Russia. While it is impossible to evaluate the price effects of a new, smaller size category, insight into the price effects were obtained by comparing predicted prices and revenues under historical conditions to predicted prices and total revenues under three different size-distribution and total harvest scenarios. The results of this analysis show that prices-by-size can change substantially and processor revenues can rise slightly or fall depending upon how management policies affect the size structure of the catch.

Conclusions about the economic effect of a reduced size-limit policy need to be considered in a broader context as discussed in the points below.

(1) Any reduced size-limit policy will have long-term biological consequences that will alter economic performance. A 1- or 2-year perspective is inadequate to judge the full merits or drawbacks of such a policy change.

(2) Processor revenues were used to indicate changes in general industry well-being, including the fishing sector. This broad inference is based on a proportional relationship between exvessel and average wholesale prices (see Matulich et al. 1990). That is, changes in average wholesale prices (revenues) transmit exvessel price changes, even though crab is not size-graded at the exvessel level. However, there are several reasons to believe that gross wholesale revenues probably overestimate processor or industry well-being. First, lowering the size limit will create a

new, smaller size category, which will face a lower price than 20/25s. Therefore, revenue estimates reported in this paper overstate the revenue that would be earned if the size limit were actually reduced. That is, presence of an even smaller crab in the domestic market should further depress earnings. Second, processor profitability is likely to shrink if the proportion of small crab increases. Per unit processing costs are greater for smaller crab. It follows that lower processing profitability should increase the margin between wholesale and exvessel levels. Third, a smaller category of king crab may compete with the much lower priced Tanner crab, *Chionoecetes bairdi*, or even golden king crab. If Tanner crab were perceived by the market as a substitute for a 25-and-up crab, the 25-and-up price would soften. Larger-pack count prices also would soften.

(3) Changes in wholesale revenues do not reflect any increase in harvest efficiency associated with higher CPUE, and a higher CPUE is likely with a lower size limit. It is conceivable, though probably unlikely, that any loss in wholesale revenue could be offset by lower per-unit fishing costs and, thus, lower exvessel prices.

A variety of caveats are appropriate with this type of analysis. Serious data limitations required model specification compromises. The most notable deficiency relates to an inability to identify buyer characteristics. For example, the data represent about 800 different customers. Yet, the top-five customers reflect 30–40% of total sales by each processor. At the very least, type and size of buyer should be incorporated into the model. This was not possible for a variety of reasons, including the inability to identify the wholesale buyers from one participating processor.

Even if model specification compromises were not required, a 2-year data series is inadequate to make reliable forecasts. Moreover, the data represent only 40% of the industry. Absence of catcher-processor data raises questions regarding the generality of implied pricing behavior. Catcher-processors are becoming relatively more important in this fishery and may exhibit different market behavior. Finally, rapid expansion of the Russian king crab fishery poses special challenges for a study of this type. Russian king crab have become a near perfect substitute for Alaska king crab. Yet, the data deficiencies encountered in this study pale in comparison to that which would be encountered if the Russian product were included in the analysis.

In sum, any consideration of a policy that alters the size distribution of crab harvests, especially a policy to lower the size limit, ought to assess the economic consequences, in addition to any biological consequences. This study provides a very conservative estimate of price-revenue consequences of a policy that would lower the size limit of Alaska red king crab. But it also serves to caution analysts and policymakers alike that formal economic analysis is fraught with data problems. For this reason, any recommendation to lower the size limit ought to involve both careful biological modeling that demonstrates beneficial, long-term stock impacts and explicit industry comment on expected economic impacts.

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